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High Resistivity Behavior of Hot-Side Electrostatic Precipitators

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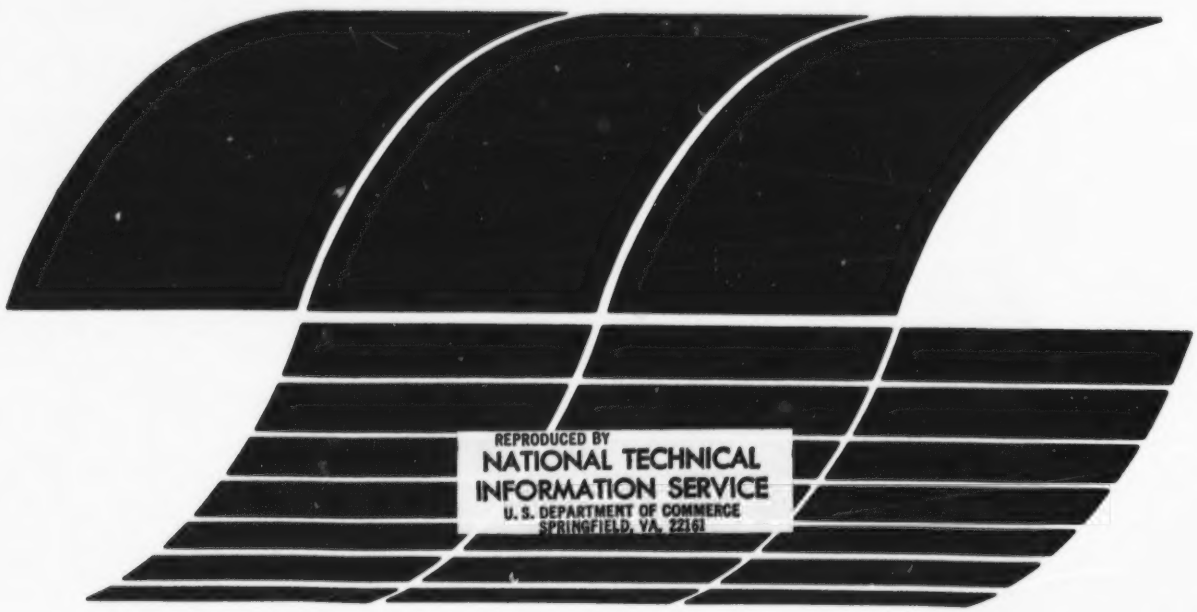

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16. ABSTRACT The report gives results of experiments to explain the high resistivity behavior of hot-side electrostatic precipitators (ESPs) collecting fly ash. The working hypothesis is that the behavior is the result of the buildup of a thin layer of sodium-ion-depleted fly ash which has a high electrical resistivity near the collector plate. The hypothesis was tested by experiments in a miniature corona discharge device under thermal and environmental conditions simulating a hot-side ESP. Current density-voltage curves were taken with positive-negative corona using a hand-placed ash layer 5 mm thick. Three major experiments were conducted to evaluate the effect on current density-voltage relationships of: long exposure to negative corona, long exposure to positive corona, and cyclic exposure to negative and positive corona. Exposure of a stationary ash layer to continuously applied negative or positive corona degraded the current density-voltage relationship. All evidence suggests that the examined hypothesis is correct. The data also indicate that some form of reversible polarity corona could remedy the difficulty. Improved rapping (to eliminate the thin adherent ash layer) or development of a suitable conditioning agent (with respect to resistivity attenuation or ash rapping and reentrainment) would be desirable.

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Cleaning	Stationary Sources	13I	
Electrostatic Precipitators	Particulate	20C	
Electrical Resistivity	Conditioning	21B	14B
Fly Ash	Rapping	11G	
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ABSTRACT

The objective of this research was to obtain evidence to prove a hypothesis explaining the time dependent degeneration of hot-side precipitator performance.

Previous research by the author had shown that electrical volume conduction through a fly ash layer is controlled by an ionic mechanism depending principally on the migration of sodium ions to serve as charge carriers. Chemical transference experiments, which are conducted under continuously applied direct voltage for a long time, revealed a significant change in the concentration of sodium ions in the fly ash that was contiguous with the electrodes. At the positive and negative electrodes, there was, respectively, a depletion and an increase in sodium ion concentration of the ash.

It was hypothesized that the time dependent, deteriorative, hot-side precipitator performance was caused by a thin film of ash adhering to the collection plates even though recommended rapping procedures were being used. Long exposure of a semipermanent, thin layer of ash to a negative corona discharge will produce a depletion of sodium ions in the ash immediately adjacent to the plate. The resistivity of the ash film becomes much greater as the sodium is depleted. This adherent, high-resistivity ash layer in series with lower-resistivity, continuously collected fly ash produces an objectionably high resultant resistivity leading to the degradation of precipitator performance with time.

A miniature corona discharge device was constructed to run experiments in the laboratory under thermal and environmental conditions simulating a hot-side precipitator. Principally, the data were current density-voltage curves taken with either positive or negative corona using a hand-placed ash layer 5 mm thick. Three major experiments were conducted to evaluate the effect on current density-voltage relationships of: long exposure to negative corona, long exposure to positive corona, and cyclic exposure to negative and positive corona.

It was observed that exposure of a stationary ash layer to continuously applied negative or positive corona caused a degradation of the current density-voltage relationship. That

is, the current density resulting from a given applied voltage decreased with time. Furthermore, it was found that the degraded relationship could be restored to the initial condition by reversing the polarity of the corona and continuously applying the reverse polarity for a time electrically equivalent to the initial polarity. Reversing corona polarity on a 24-hour schedule apparently inhibited degeneration of the current density-voltage relationships. Since a stationary ash layer was used, the ash nearest the corona wire was not periodically replaced as in a precipitator. Because of this, there was ambiguity with respect to the reason for the degradation of the current density-voltage relation when positive polarity was used. Degradation could result from the sodium depletion in the ash nearest the discharge electrode or from the build-up of these ions in the ash nearest the "collection" electrode.

All evidence obtained suggests that the hypothesis stated above is correct. Furthermore, the data indicate that some form of reversible polarity corona could remedy the difficulty. Obviously, steps taken to improve rapping to eliminate the thin adherent ash layer or to develop a suitable conditioning agent with respect to resistivity attenuation or ash rapping and reentrainment would be desirable.

This report is submitted in partial fulfillment of Contract 68-02-2610, Task 10 by Southern Research Institute under sponsorship of the U.S. Environmental Protection Agency. This report covers the period October 1, 1978, to March 10, 1979, when it was completed.

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Mr. Sabert Oglesby, Jr. introduced the author to the subject problem and vigorously supported this work. The author is grateful for the opportunity to conduct this research and appreciates the helpful conversations held with various colleagues.

SECTION 1

INTRODUCTION

High electrical resistivity has a significantly adverse effect on the dry, electrostatic collection of fly ash. At a typical cold-side precipitator temperature of 150°C, fly ash produced from low-sulfur (<1%), low-sodium (<1%) coal will typically have a resistivity value in the range 1×10^{11} to 5×10^{12} ohm cm. Of the several options available with which the elevated resistivity can be combated, one is the use of hot-side precipitation. The selection of this option has increased in recent years. Between 1967 and 1977, approximately 150 hot-side precipitators were purchased. These units are associated with 25 percent of the total electrical generating capacity of the coal-fired boilers purchased with precipitators in this period.[1] Hot-side precipitators normally operating at 350°C are used, because the resistivity of the above described fly ash is usually in the range of 1×10^{9} to 5×10^{10} ohm cm at this temperature.

The increased usage of hot-side precipitators brought forth problems, usually associated with poor performance, previously not observed or, at least, little discussed. A principal observation was the degradation of precipitator performance as a function of time. When clean, the precipitator functions well; however, after several weeks of operation, performance gradually becomes poor with the advent of back-corona. After the precipitator is thoroughly cleaned, good performance returns. One of the most intriguing observations was current density-voltage curves indicative of back-corona occurring concomitantly with in situ and laboratory resistivity values of about 5×10^{9} ohm cm.

This report describes research conducted to determine the explanation for the above described behavior and to suggest possible remedial steps to improve performance.

SECTION 2

SUMMARY AND CONCLUSIONS

It has been observed that the performance of certain hot-side electrostatic precipitators degrades as a function of time. Thorough washing of the precipitator restores the desirable performance only to attenuate again with time. This degradation often is concomitant with evidence of back-corona although *in situ* measurements suggest no resistivity problems. Cursory laboratory experiments and additional field observations showed that explanations for the above behavior based on the effect of reduced pressure at high altitude or decreased dielectric strength at hot-side temperatures were not satisfactory.

It was hypothesized that the observed performance is a manifestation of electrode polarization. If the rapping process is imperfect and a thin layer of ash collected using negative corona remains on the collection plate, this layer will become essentially void of mobile, postive charge-carrying ions (sodium). Since the collection plate is a blocking electrode; that is, incapable of supplying the charge carrying species, it is termed polarized. Depending on technical discipline, this can be referred to as sodium depletion or an ash layer space charge effect. This effect should occur due to imperfect rapping for hot-side and cold-side precipitators that depend on sodium concentration for electrical conduction rather than adsorbed sulfuric acid vapor. When the thin layer of ash tenaciously adhering to the collection plate in spite of rapping has been exposed to the electrical field for a sufficiently long time, conduction through the layer is limited to a mechanism other than sodium migration; for example, the migration of anions such as oxygen. This thin layer having very high resistivity develops sufficiently high field strength near the plate to cause dielectric breakdown. This hypothesis was based on literature to be cited later that: a) suggested the possibility of the electrode polarization problem, b) showed the attenuation of current with time of applied electrical potential, and c) determined that a sodium concentration gradient was produced in an ash layer subjected to long-time direct current electrical potential at both cold-side and hot-side temperatures.

Since the hypothesis was based on evidence obtained using parallel plate resistivity cells and temperatures both above and below normal hot-side precipitator operation, additional

information was desired. The data herein reported were obtained at 350°C using a small, wire-plate corona discharge device containing a hand-placed layer of fly ash. Three experiments were conducted in which the effect of: a) long-time exposure to negative polarity corona, b) long-time exposure to positive polarity corona, and c) cyclic exposure to negative and positive polarity corona for various time increments were evaluated by determining either negative or positive current density-voltage curves at appropriate times.

None of the data obtained conflict with the above hypothesis. Current density-voltage curves were made to degrade as a function of time of applied electrical field for coronas of positive or negative polarity. Furthermore, the degraded current density-voltage curves could be restored to the initial condition by reversing the polarity. The data also illustrated the phenomenon of storing charge carriers using one polarity to delay the degradation of the current density-voltage relationship for the opposite polarity. For an ash of relatively high inherent resistivity, the data showed that in a short period of time (3 to 6 days), a condition suggesting back corona could be developed. These observations in which the current density decreases as a function of time of electrical field application are identical to those found with parallel plate resistivity cells and are the result of the ionic conduction mechanism in fly ash and the use of blocking electrodes.

SECTION 3

REMEDIAL CONSIDERATIONS

Under certain conditions a thin, essentially continuous layer of fly ash adheres to the collection plates even though good rapping technique is employed. This layer of fly ash is consequently subjected to an electrical field for a relatively long time. Since electrical conduction through the layer at hot-side temperatures is dependent on a finite concentration of charge carriers (sodium ions), prolonged exposure to the electrical field causes a significant increase in the resistivity of the layer due to the migration of the charge carriers out of this zone.

The situation can be aggravated in several ways. Anything that can contribute to ineffective rapping is undesirable. The rapping interval and intensity should be optimized and plate alignment, linkage and suspension should be in proper working order to transmit the rapping energy to the ash layer.

Usually the subject problem is associated with hot-side precipitators designed to operate at 350°C (660°F) and higher. Whether one is considering the initial condition or after precipitator performance has degraded, the conduction process through the ash layer is thermally activated. Therefore, lower precipitator temperatures will produce higher resistivity values.

The character of the fly ash can also affect the precipitator performance degradation. To circumvent high resistivity under cold-side conditions, hot-side precipitators are often installed when design coals will produce insignificant concentrations of sulfuric acid vapor in the flue gas. When these coals also produce fly ashes with small concentrations of sodium, resistivity can be high even at hot-side temperatures. The greater the inherent resistivity of the fly ash, the more quickly a situation of degraded performance can develop and the more severe will be the problem. Another ash characteristic of importance is interparticle cohesion and ash-layer density. Fly ash composition and particle size distribution influence these factors. Low density particulates of extremely small particle size can produce collected layers of low density and little cohesion. These layers are difficult to rap as a sheet into the collection

hoppers. A thin layer of ash is often left on the plates. Fine, low density ashes high in alkaline-earth elements such as calcium and low in iron concentration characterize these difficult ashes.

At the present time, only a thorough cleaning of precipitator electrodes positively relieves the subject difficulty for a short time. The specific and general approaches cited below toward the solution of the problem are intended only for the reader's consideration and investigation. Potential remedial solutions have yet to be proved.

• Reversible polarity corona - In this report the experiments used to demonstrate the cause of the problem also suggest a potential solution. The periodic use of positive polarity corona causes the migration of sodium ions into the ash layer depleted of these ions during the use of negative polarity corona. Thus a discharge electrode design with systematic reversible polarity could balance the migration of sodium near the collection plate yielding an average performance superior to that of a completely degraded system using continuously negative corona.

• Continuous positive corona - This system would have the inherent disadvantages of lower current density for a given voltage in comparison to negative corona. It was also shown in this report that the current density-voltage relationship for positive corona degrades with time. However, it is not known whether this degradation is related to a depletion of sodium ions at the ash surface nearest to the corona wire or whether it is due to a build-up of sodium ions at the "collection plate." In a precipitator only the latter occurrence would present a problem since it is only the ash immediately adjacent to the plate that is of concern. A difficulty associated with a build-up of sodium at the ash-collection plate interface would require a sink for the sodium; for example, perhaps a carbon-cladded collection plate.

• Continuous negative corona with novel collection plate design - An innovative collection electrode design incorporating a source of charge carriers would overcome the depletion of sodium ions in the adjacent ash layer. The most elementary approach to this solution would be the deposition of a sodium bearing compound on the collection plates using a washing technique.

• Improved rapping technique - Perhaps truly clean collection plates can be produced by conventional rapping if: a) materials and surface finish are altered, or b) a "soot" blowing device is designed to periodically blast the collection plate surfaces.

• Conditioning - Potential coal or flue gas additives that are thought to cause densification, agglomeration or increased cohesiveness of the ash to promote better rapping should be given consideration.

Conditioning to attenuate resistivity should also be effective. The potential agents are compounds with which sodium or other charge carrying ions can be added to the fly ash. Sodium compounds can be introduced dry or as solutions to the flue gas or to the coal feed. It should be emphasized that this conditioning technique is sensitive to the degree of intimacy attained between the agent and the fly ash.

If the compound is added to the flue gas and the agent does not decompose, one probably must depend on coprecipitation of fly ash and conditioning compound to develop an ash layer having lower resistivity. If the coprecipitated material is not homogeneous or if it is simply deposited on a high-resistivity, sodium-depleted layer, one would not expect effective conditioning. However, if a reasonably homogeneous, coprecipitated layer is deposited on clean plates, it is possible that satisfactory operation can be extended to a tolerable length of time. It is conceivable that this type of conditioning would only be required during start-up after outage for precipitator cleaning.

If the conditioning agent is added to the coal feed and the compound decomposes or is volatilized, fine sodium-rich particulates can form or a vapor can condense on the fly ash surface. In either case one should find the conditioning species intimately associated with almost all fly ash particles. This mode of conditioning probably would require less additive than in the case of flue gas injection, and as described above, may be required only during start-up. It is also conceivable under these conditions that the intrinsically conditioned ash could serve as the driving force for the chemical diffusion of the sodium toward the collection plate thereby compensating for the existing sodium-depleted zone that results from the effects of the electrical field. If this mechanism is operable, one should observe some improvement in precipitator performance after operating a unit for some period of time at temperature but electrically deenergized.

Presently preliminary field experiments are being conducted for remedial procedures involving polarity reversal and sodium conditioning.

SECTION 4

BACKGROUND

Initial reports[2,3] of the symptoms of poor performance defined above came from installations in the western part of the United States located at altitudes of 5000 feet. This led to the rationalization that reduced atmospheric pressure played a role by permitting dielectric breakdown of the interstitial gas in the ash layer at lower than normal field strengths.

It was also suggested that the higher temperature associated with hot-side precipitators caused a decrease in dielectric strength. If true, the allowable value of resistivity for a desirable oocurrent density would be reduced from the value normally considered acceptable for cold-side operation.

Careful consideration suggested that these views be evaluated even though it was known that the degradation in performance was time dependent. Subsequently, poor hot-side precipitator performance having the same symptoms as the units at high altitude occurred at sea level.

Before conducting the principal research efforts reported herein, a few cursory experiments were executed at reduced pressures and elevated temperature to examine the effect of pressure and temperature on resistivity and dielectric failure. The tests were run at 350°C using apparatus previously described.[4] The environment was a simulated flue gas containing 9 percent water and no sulfur oxides. The pressure in the environmental chamber was determined by a manometer and controlled with a vacuum pump and leak valve. The fly ash used had a resistivity of about 2×10^9 ohm cm and was obtained from a unit experiencing the subject difficulties.

Figure 1 illustrates the average field strength at electrical failure as a function of pressure for ash layers approximately 2 and 7 mm thick. The data show that the field strength for dielectric failure decreases linearly with decreasing pressure. The decrease in field strength for failure associated with a pressure change from 760 to 635 mm of mercury is insignificant with respect to the problem being considered. The single data point at a pressure of 635 mm of mercury using a 2 mm thick specimen was obtained to illustrate that under these conditions of pressure and temperature, a high dielectric failure stress was possible. The lower values associated with the thicker ash layer are typical for laboratory resistivity specimens, while the value

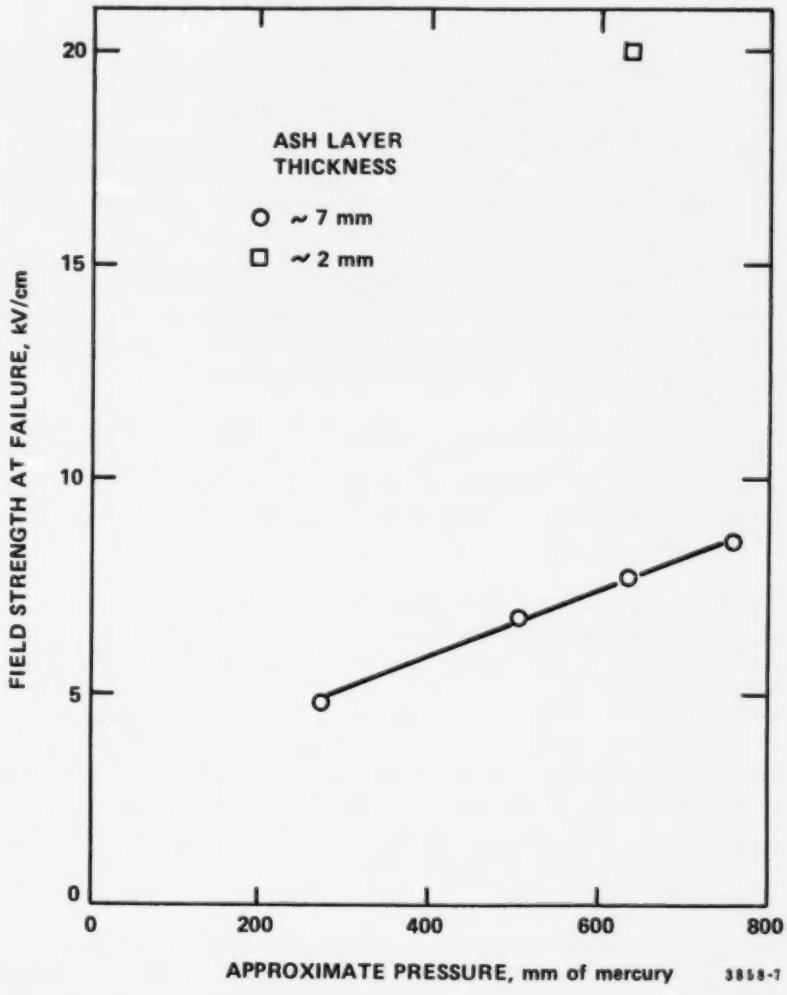

Figure 1. Dielectric strength versus environmental pressure at 350°C.

for the thin specimen is typical for in situ resistivity specimens. The increase in dielectric strength as the test specimen thickness decreases is commonly observed for ceramic insulating materials.

Resistivity was also determined as a function of environmental chamber pressure. These data are shown in Figure 2. Current readings just prior to dielectric breakdown were used to calculate resistivity. Since the electrical field causing dielectric failure decreased with decreasing pressure, the current measurements with which resistivity was calculated were made at successively lower electrical field strengths. Therefore, the increase in resistivity as a function of decreasing pressure shown in Figure 2 is likely a manifestation of the lower electrical fields associated with the lower pressure.

In the tests described above, the voltage was always applied for 1 minute before a current reading was taken or a higher voltage was applied. Subsequently, dielectric failure tests were run at 350°C and a pressure of about 500 mm of mercury using the above mentioned fly ash and another fly ash having a resistivity of 1×10^{11} ohm cm. The ash layers were about 7 mm thick. In these tests, each successively higher voltage was applied for 1 hour instead of 1 minute to determine any tendency for electrical fatigue. The ash with the higher resistivity failed immediately at 4000 volts in both tests. The ash with the lower resistivity failed immediately at 4700 volts using the 1 minute application and failed at 4000 volts after 6 minutes of the 1 hour application. Although these data do not suggest a strong tendency toward electrical fatigue, additional tests for long periods of time are needed to evaluate this point.

The results of the superficial experiments detailed above do not conflict with the observations that: a) the subject hot-side precipitator problem can be transiently eliminated by washing and, b) the problem happens at all altitudes. It was concluded that some phenomenon other than the effect of temperature and pressure was responsible for the time dependent degradation of hot-side precipitator performance.

Early in 1978 the writer suggested that the characteristic observations regarding poorly performing hot-side precipitators could be caused by electrode polarization. Depending on one's technical discipline, this phenomenon also can be referred to as sodium or carrier ion depletion, or as a space charge event. Whatever name is applied, the phenomenon involves the migration of charge carrying ions of limited, inherent concentration under an applied direct current voltage to create a region or zone depleted of charge carriers which produces an ash layer having higher resistivity. This phenomenon was described[5] previously in detail with respect to ionic conduction through precipitated ash layers.

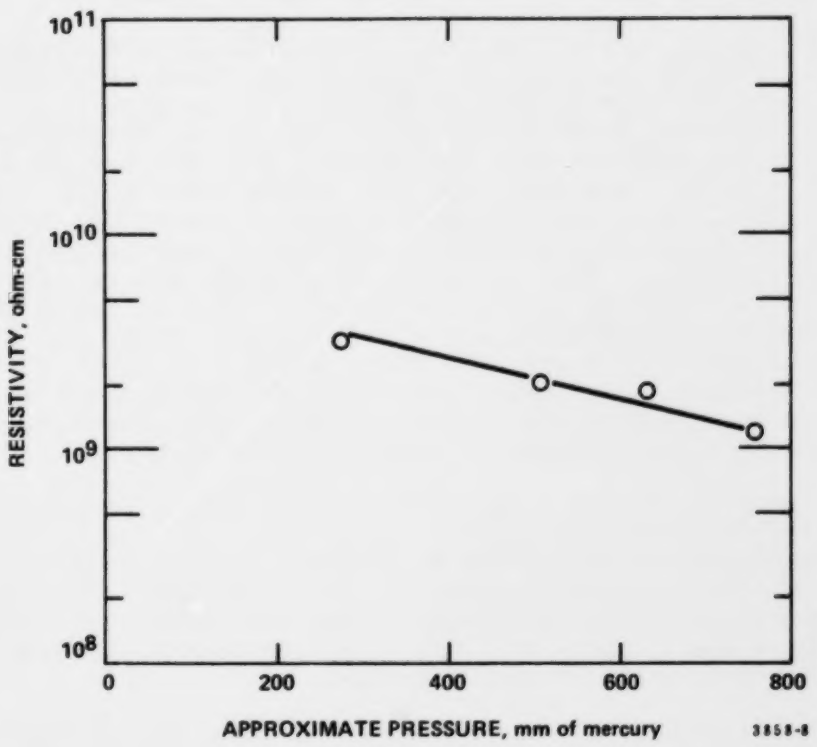

Figure 2. Resistivity at electrical failure versus pressure.

Briefly with respect to fly ash and hot-side, negative corona precipitation, the following event would occur. Sodium ions in the collected ash layer migrate toward the discharge electrode. No excessive build-up of sodium would be expected because charged particles are constantly being added to the collected layer and ash is being rapped off. However, at the positive collection plate, a different situation exists. As the sodium ions migrate away from the anode, the conduction process becomes dependent on another ionic mechanism that requires more energy to activate. Therefore, that portion of the ash layer contiguous to the collection plate develops a resistivity much greater than the remainder of the collected layer. The collection plate can be described as a "blocking electrode" because it is incapable of supplying charge carriers; in this case, sodium ions.

The normal electrical manifestation of this situation is an attenuation of current as a function of time of applied voltage. This was observed when chemical transference experiments[5,6,7] were conducted both at 60°C and 600°C. The phenomenon will take place under cold-side or hot-side conditions if the conduction process is primarily dependent on the inherent, limited concentration of charge carrying alkali metal ions in the ash.

Figure 3 illustrates the above described effect. When the circuit was initially closed, a current density in excess of 100 nanoamps/cm^2 resulted. After 140 hours of continuously applied voltage, the current density asymptotically approached a value of <10 nanoamps/cm^2. This time dependent degradation of current carrying ability is similar to the problem faced with certain hot-side precipitators. The apparent lower limit for current density is related to the development of a stable layer of ash through which conduction no longer depends on the presence of mobile alkali metal ions.

The data shown in Figure 3 were acquired at 350°C using an ASME, PTC-28 resistivity cell containing an ash layer 3 mm thick having a resistivity value of about 1×10^9 ohm cm. After the test was completed, it was determined that the current through the ash layer varied exponentially with a decrease in voltage from the maximum applied and that the experimental activation energy for volume conduction had increased from 0.7 electron volts to 1.1 electron volts. It is assumed that the later activation energy is associated with the rate controlling conduction mechanism prevailing after the sodium ions have been depleted in the ash layer adjacent to the anode.

It was hypothesized that the above described phenomenon can be responsible for the time dependent decay of precipitator performance. All that is required is that a layer of ash contiguous to the positive collection plate is not removed by rapping. If a film of ash remains on the plates for a long period of time,

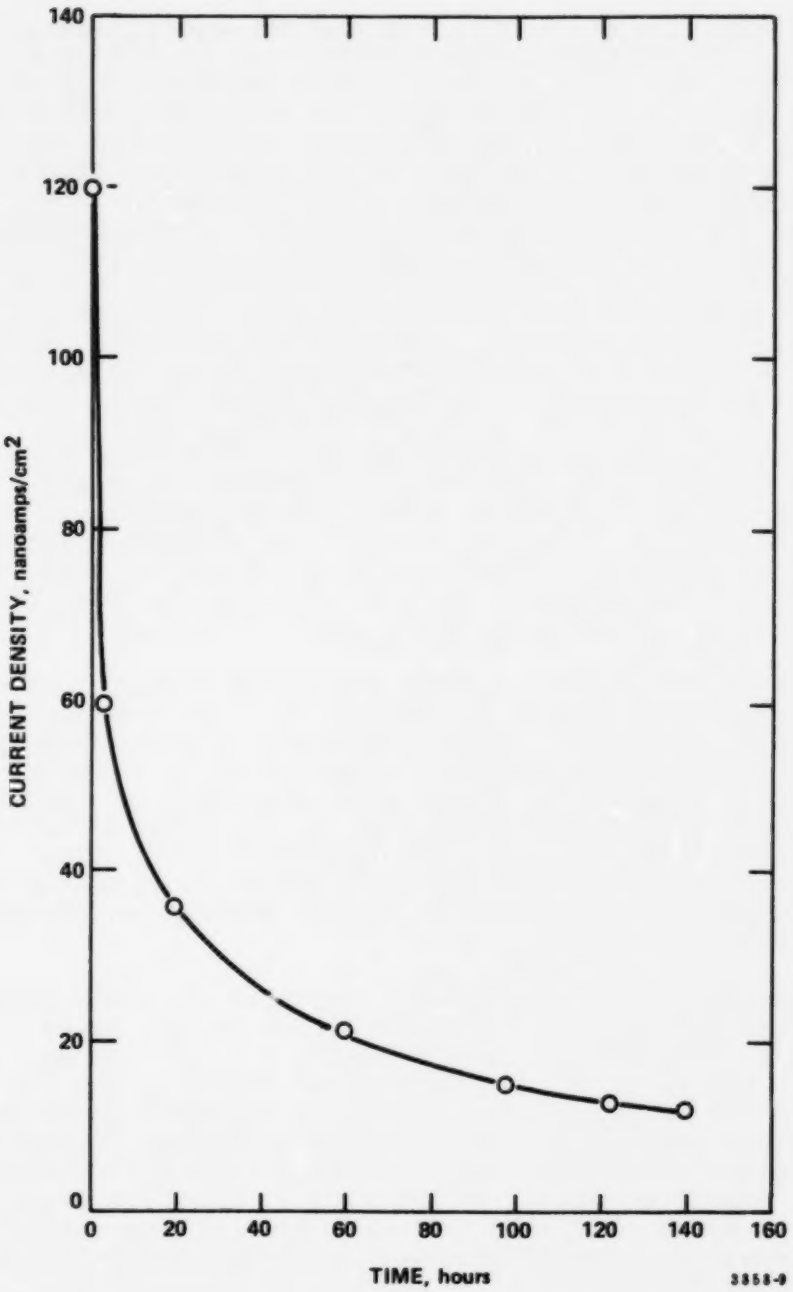

Figure 3. Attenuation of current density with time of continuously applied direct current voltage; parallel plate resistivity test cell.

the current carrying capacity will degrade. Poor rapping design, low ash-layer density, low interparticle cohesion, high electrostatic attraction of the ash to the plate, and high adhesion of the ash to the plate will aggravate the situation.

The initial experiment described above was accomplished with a resistivity test cell. This report is concerned with the effort to verify the hypothesis using a small wire-plate corona discharge device. The objective was to demonstrate the degradation of current density-voltage curves toward positions of higher resistivity and symptoms of back corona as a function of time of applied voltage. This was to be accomplished for both positive and negative corona. It was also desired to demonstrate that the effect is reversible.

SECTION 5

EXPERIMENTAL EQUIPMENT AND PROCEDURES

The general resistivity test apparatus described in reference 4 was used in this work. The environmental chamber was altered to accept the electrical feed-throughs for the wire-plate corona discharge device, and a reversible-polarity, direct-current voltage source having a capacity of 50 kV was installed in place of the more precise, lower capacity source used for resistivity determinations. In all tests, the environment was a simulated flue gas containing 9 percent water and no sulfur oxides maintained at 350°C. Figure 4 shows a schematic of the wire-plate corona discharge device. The materials used, critical dimensions and electrical circuitry are self-explanatory in the figure.

After initial short term experiments were conducted to establish the optimum test conditions and determine current density-voltage curves for negative and positive polarity under clean-plate conditions, three long term experiments were run.

EXPERIMENT 1.

The objectives of this experiment were to demonstrate the degradation of a current density-voltage curve as a result of a continuously applied negative corona and to determine if the application of positive voltage for a period of time would restore the current carrying capacity of the ash layer. After the ash was placed in the test cell shown in Figure 4, the apparatus was thermally equilibrated at 460°C for 16 hours in dried nitrogen. The apparatus was then thermally equilibrated at 350 C in the presence of the previously described simulated flue gas environment. A negative corona was established, and the initial current density-voltage curve was determined. After data for this curve were obtained the corona voltage was set to an arbitrarily selected value of 10 kV (negative) to continuously apply a voltage drop across the ash layer. The resulting current flow was monitored. Current density-voltage curves were obtained at least one time every 24 hours. The voltage was reset to 10 kV after each determination. After negative corona had been applied for 192 hours, the final current density-voltage curve was taken, and the polarity was then reversed to positive. After 90 hours of positive corona with positive current density-voltage curves being periodically

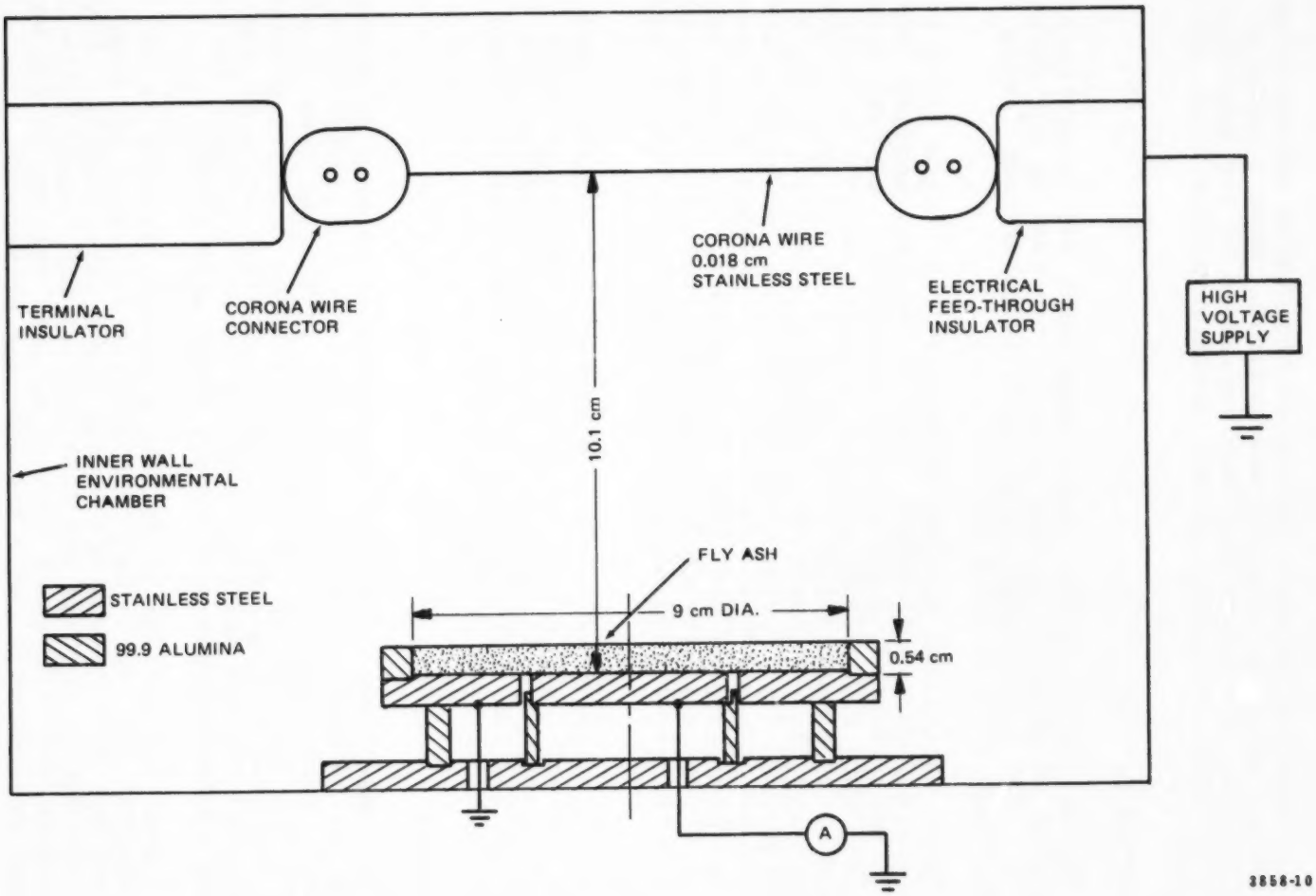

Figure 4. Schematic and electrical circuit diagram for wire-plate corona discharge device.

taken, a negative current density-voltage curve was established after which positive polarity was resumed. When a total of 168 hours of positive corona had been impressed on the specimen, the final negative corona current density-voltage curve was obtained.

EXPERIMENT 2.

The objective of the second experiment was to determine the effect of periodic corona polarity reversal on the current density. The preliminary steps taken in experiment 2 were identical to those used in experiment 1.

After an initial current density-voltage curve using negative polarity was established, the continuously applied negative voltage was selected to produce 15 nanoamps/cm^2 current density. After 24 hours had passed, another negative current density-voltage curve was obtained. The polarity of the applied voltage was then reversed to positive. A current density-voltage curve was taken, and the continuously applied positive voltage was selected to give a current density of 15 nanoamps/cm^2. After 24 hours had elapsed, both positive and negative current density-voltage curves were recorded. These data were then compared with curves established after the first 24 hour cycle of negative polarity.

For a period of 320 hours, a sequence of polarity reversals was maintained. The number of hours that a given polarity was used was varied. Principally, an attempt was made to show the effect of shortening the period of positive polarity between two extended periods of negative polarity.

EXPERIMENT 3.

The objectives of the third experiment were to determine if the use of positive polarity would lead to a condition of electrode polarization and what effect this might have on subsequent current density-voltage curves using negative polarity. As in the case of experiments 1 and 2, a fresh layer of high resistivity fly ash was placed in the corona discharge device, and the aforementioned preliminary steps were taken.

A positive voltage to produce a current density of 15 nanoamps/cm^2 was maintained continuously for about 120 hours with current density-voltage curves taken periodically. After this, the corona voltage was reversed and maintained again at 15 nanoamps/cm^2. Negative current density-voltage curves were obtained periodically until the test was terminated.

SECTION 6

RESULTS AND DISCUSSION

When an electrical field is maintained across a layer of ash for an extended period of time, the current conducted through the layer will gradually diminish, asymptotically approaching some minimum value. This was illustrated in Figure 3 for an ash layer sandwiched between parallel plates in a resistivity test cell. In Figure 5 similar data are shown for a 5 mm thick ash layer resting on a "collection plate" exposed to a corona wire at a negative 10 kV potential. At time zero the current density is commensurate with the inherent conductivity of a "freshly collected" layer of ash on a previously clean collection plate surface. This is shown for two fly ash layers having different electrical conductivities due to variation in sodium concentration. These hand-placed, stationary layers of ash are meant to simulate the situation in which a layer of ash on a collection plate of an electrostatic precipitator fails to dislodge and fall during rapping. As the time of exposure to the electrical field increases, the current density decreases.

It has been hypothesized that the attenuation of current density is a result of the depletion of charge carrying ions, principally sodium, in a very thin film of ash at the anode (collection plate) surface and the concomitant build-up of these ions at the ash layer surface nearest the negative corona wire. This distribution of charge carriers is schematically illustrated in Figure 6. In practice this situation results from a thin film of ash remaining on the plates after rapping.

It can be assumed that the initial concentration of mobile charge carrying alkali metal ions, C_1, is adequate to produce a resistivity of 1×10^{10} ohm cm and that an ash layer 5 mm thick has been collected. Because of the failure to rap cleanly, a layer of ash depleted of positive charge carriers develops up to the distance x. If it is assumed that this layer depleted of positive charge carriers is about 0.05 cm thick and that the average resistivity for this region is 1×10^{13} ohm cm, then it can be calculated that the resistivity of the entire 5 mm thick layer is about 1×10^{12} ohm cm. The localized field strength in this region can be great, leading to dielectric failure even though the dielectric strength of this region may have been enhanced. This example suggests an explanation for back corona

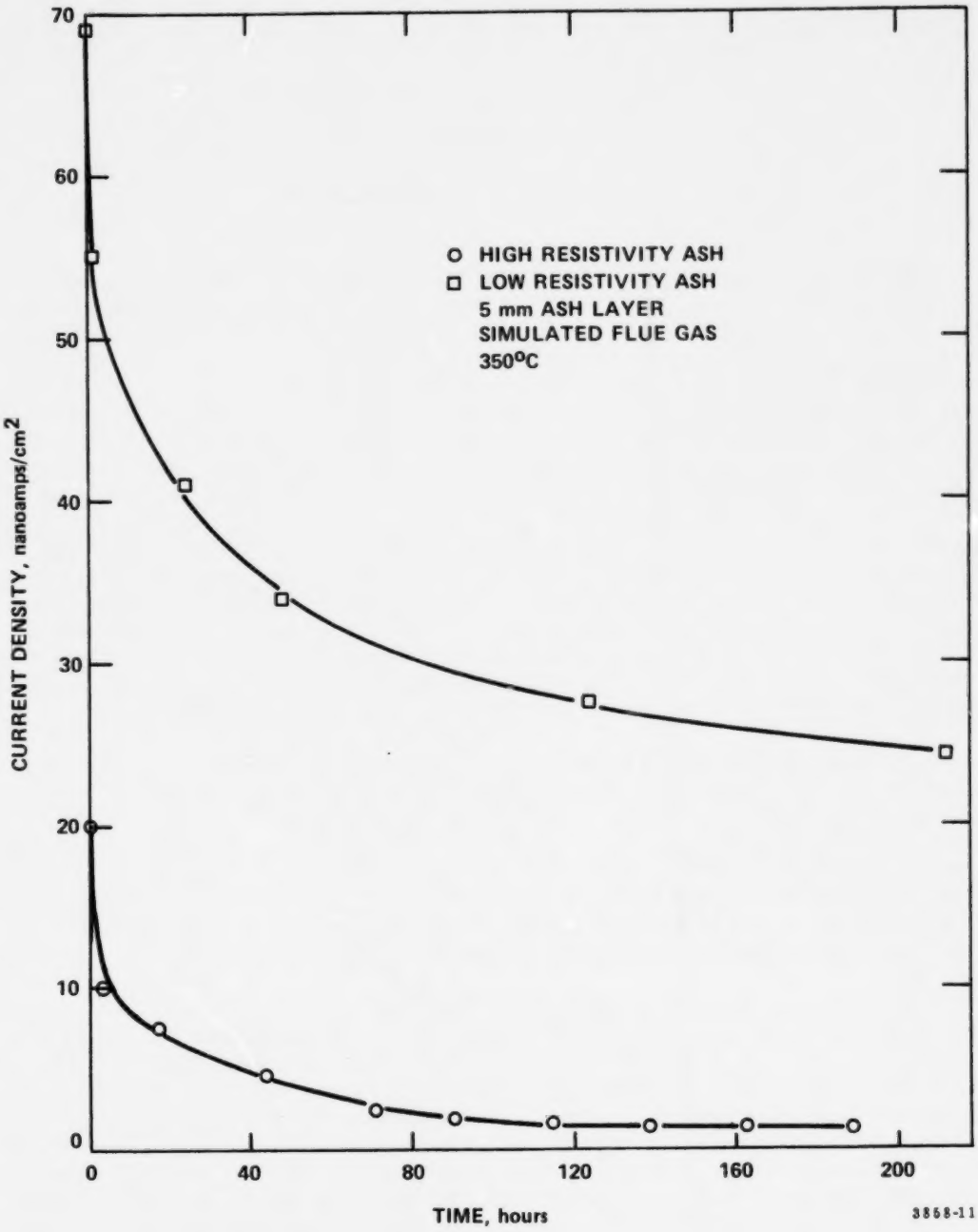

Figure 5. Current density as a function of continuously applied negative corona, 10 kV.

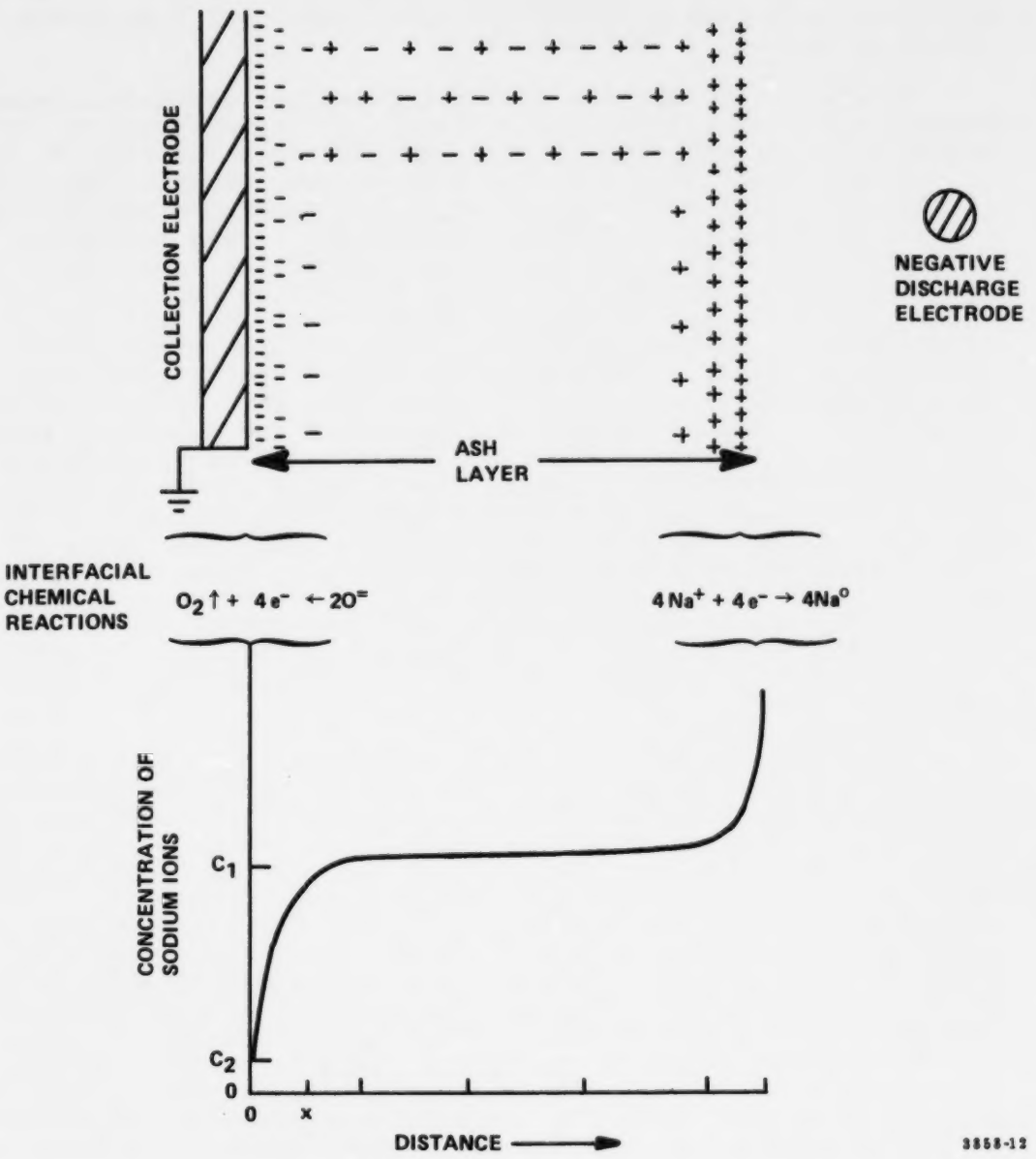

Figure 6. Distribution of charge carrying ions in an ash layer after long-time exposure to an applied direct current voltage.

being observed, while in situ and laboratory resistivity determinations made over a relatively short period of time yield values of about 1 x 10^{10} ohm cm.

Electrical conduction does not cease but approaches some minimum value as illustrated in Figure 5. After there is little decrease in current-density with the additional passage of time, it can be assumed that a stable film of ash, essentially void of mobile, positive charge carriers, has developed and that conduction is dependent on another mechanism. Glass technology suggests that under these conditions conduction takes place via the migration of oxygen ions toward the collection plate resulting in the formation of neutral oxygen molecules with the release of electrons. Because of the low concentration of unassociated and unbound oxygen atoms and the increased energy requirements, the resistivity of this thin ash film is great. It can be speculated that "minimum" current densities for the two ashes shown in Figure 5 will remain separated because the ash with the greater initial concentration of mobile alkali metal ions will necessarily have a greater number of mobile oxygen ions. Suitable electrochemical expressions are given in Figure 6 to illustrate the charge exchange at the ash layer boundaries while maintaining electrostatic balance in the system. In the subsequent discussion an attempt is made to analyze the results of the three previously described long-time experiments in terms of the above interpretation regarding electrode polarization or sodium depletion.

The initial experiment involved a layer of high resistivity fly ash being exposed first to a negative corona for a long time followed by exposure to a positive corona. The effect was evaluated by periodically obtaining either negative or positive current density-voltage curves. In Figure 7 the initial negative current density-voltage curve, A, was obtained after the negative voltage corona had been on for 6 minutes. Comparing this with the clean-plate curve indicates that the fly ash had a relatively high inherent resistivity. After impressing the negative 10 kV corona on the ash layer for 192 hours, the negative current density-voltage curve, B, was obtained. The dramatic shift to lower current density for a given voltage illustrates the increase in effective resistivity for the ash layer. At this point, the fly ash contiguous with the "collection electrode" was depleted of mobile sodium ions and the ash surface nearest the negative corona wire contained an excess of these ions, as depicted in Figure 6. Current density for a constant voltage had reached a "minimum" value with respect to time. Without physically disturbing the apparatus, the polarity was reversed, and after 90 and 168 hours of continuously impressed positive corona, the negative current density-voltage curves, C and D, respectively, were taken. After 90 hours of positive polarity, the negative

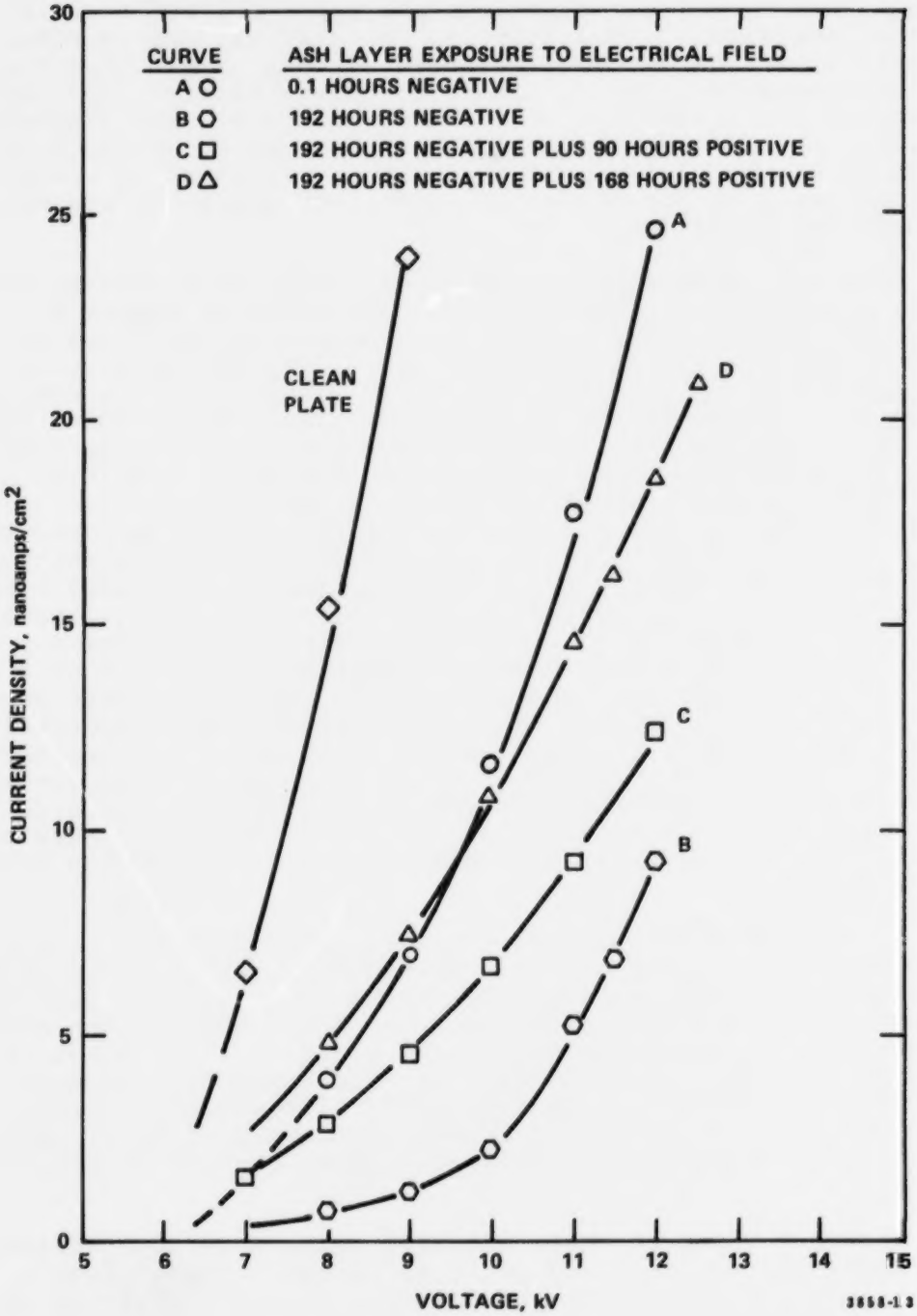

Figure 7. Current density as a function of applied negative voltage.

current density-voltage curve was partially shifted back to its original position. The shift to the original position was complete after 168 hours of positive corona. These observations are interpretable using the depleted charge carrier idea, and the events are reversible by changing polarity. The distorted distribution of charge carrying ions produced by an electrical potential of one sign apparently can be eliminated by changing polarity until an approximately equivalent charge is passed in the opposing direction.

Positive voltage-current density curves were also obtained during experiment 1. These results are shown in Figure 8. The distorted carrier ion distribution produced by 192 hours of continuous negative corona also adversely affected the current carrying capacity under positive polarity. The ash surface nearest the corona wire contained an excess of alkali metal ions, the positive charge carriers. The first positive corona current density-voltage curve, A, in Figure 8, showed an undesirable situation. As the time of continuously applied positive voltage was increased, the current density-voltage curves improved to B and then C. It is believed that continued positive voltage would ultimately cause curve C to degenerate back toward B as the carrier ion concentration becomes distorted in the opposite direction. This point will be demonstrated when experiment 3 is discussed below. Comparison of curve C in Figure 8 with Curve A in Figure 7 shows the inherently lower current density produced by positive corona for a given voltage in contrast to negative corona. The greater current density produced by a given negative corona voltage is probably due to the presence of free electrons in addition to negative ions to serve as charge carriers in the interelectrode space.[8] This observation may be exaggerated because of the rather small distance between discharge and collection electrodes.

The observation that the undesirable degradation of current density-voltage curves can be arrested by a change in polarity suggested the second experiment. Again negative and positive current density-voltage curves were used to evaluate the effect of periodically reversing the corona polarity. Variation in the time increment for each polarity was examined. Because of the lower current densities associated with positive corona, it was of interest to see if relatively long periods of negative corona could be used with relatively short periods of positive corona.

Figure 9 shows the data acquired using a 24 hour schedule of alternately negative and positive corona. Twenty-four hours of continuously applied negative corona caused a shift in the negative current density-voltage curve from A to B. At this point the voltage was reversed to positive, and the curve labeled

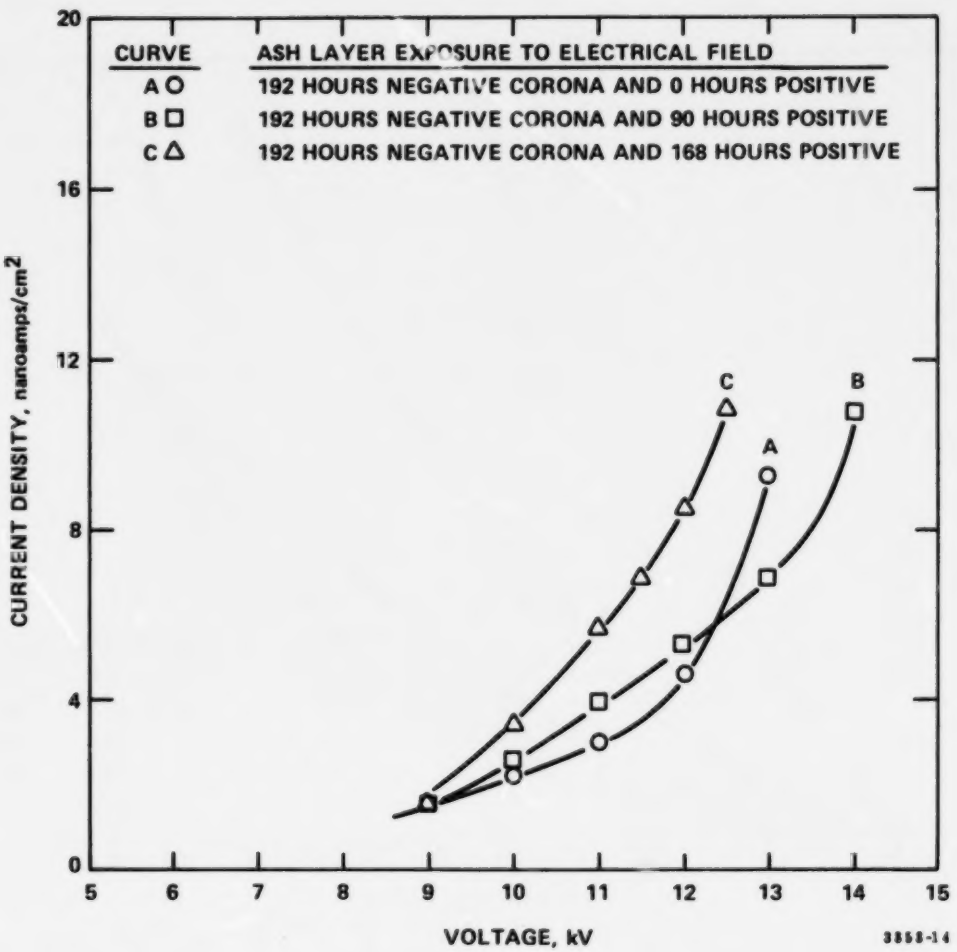

Figure 8. Current density as a function of applied positive voltage.

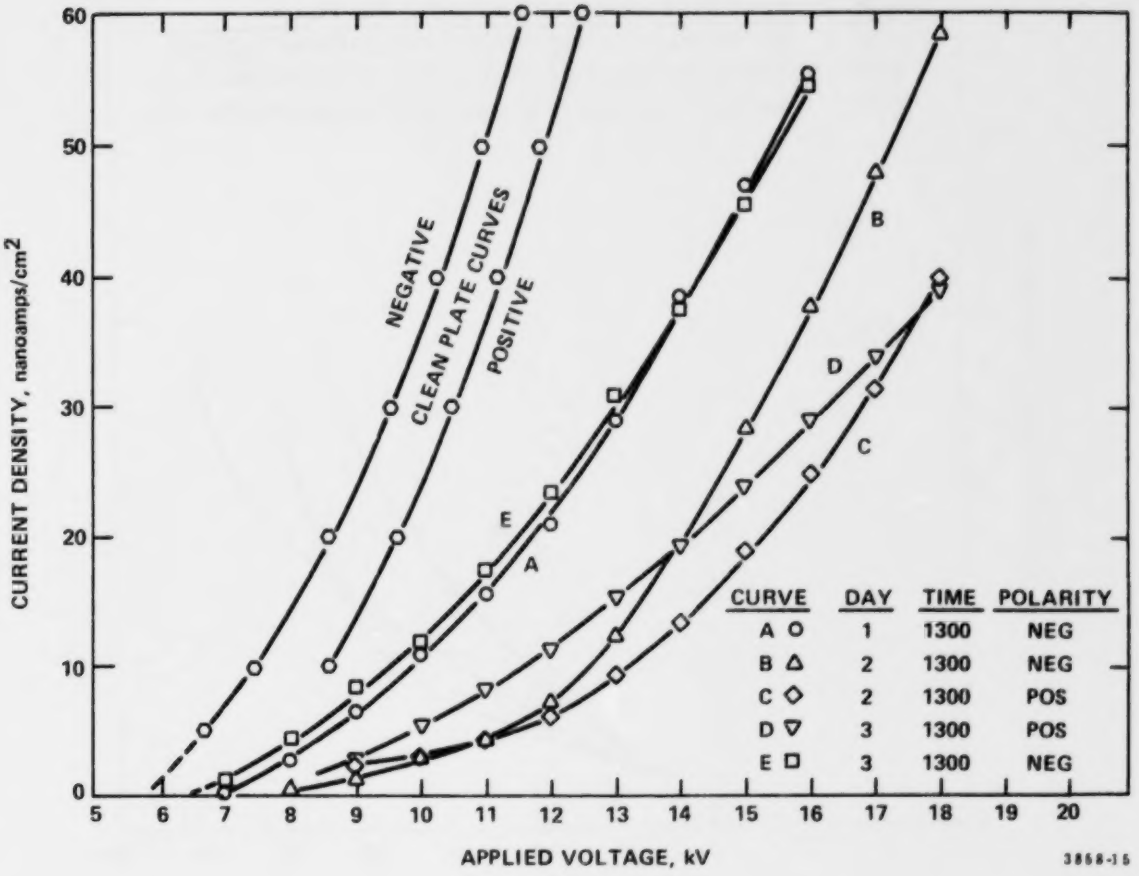

Figure 9. Influence of corona polarity reversal on current density - voltage curves.

C was obtained. After twenty-four hours of continuously applied positive corona, the positive curve D and the negative curve E were obtained. Apparently the negative current density-voltage relationship which had been degraded by a continuous negative potential producing a current density of 15 nanoamps/cm^2 could be restored by operating under positive corona for a similar length of time and current density.

Figure 10 shows the results obtained when the time increment for negative potential was maintained at 20 to 24 hours while the time increment for positive potential was decreased from 24 to 4, then 2, and then 1 hour. For two cycles while the positive increment was 4 hours (Figure 10 abscissa, about 100-160 hours), it would appear that the negative current density-voltage relationship was being reasonably restored. However, when the positive cycle was reduced to 2 hours and then 1 hour (Figure 10 abscissa, about 160-200 hours), the negative current density did not return to its initial highest level and, with respect to time, quickly fell to its lower level. In the later stages of the experiment, the positive cycle was lengthened again to 24 hours. The current density values for negative corona once again approached their initial condition.

It would intuitively seem that the quantity of electricity passed using positive polarity would have to equal that passed under negative polarity to restore the negative current density-voltage curve to an initial condition. However, the results shown in Figure 10 do not completely substantiate this point, and the issue deserves additional examination. It should also be considered that in practice the positive corona would not have to overcome a surface saturated with positive charge carrying ions, because the surface layer of collected ash nearest the corona wire is probably renewed by the sequence of rapping and additional collecting.

A third experiment was conducted to demonstrate the effect of a long-time exposure to positive corona using fresh fly ash. The experiment was essentially identical to the first experiment described except that the initial corona was positive. The results are shown in Figure 11.

The first positive current density-voltage curve, A, was taken a few minutes after the start of positive corona. After approximately 120 hours of continuously applied positive polarity corona at a current density of 15 nanoamps/cm^2, the positive current density-voltage curve, B, was obtained. The degradation of the current density-voltage relationship shown by curves A and B was expected due to the distortion of the charge-carrying ion distribution. In this case, a deficiency of sodium ions at the surface nearest the corona wire and an excess at the "collection plate" would occur. It is believed that curves C in

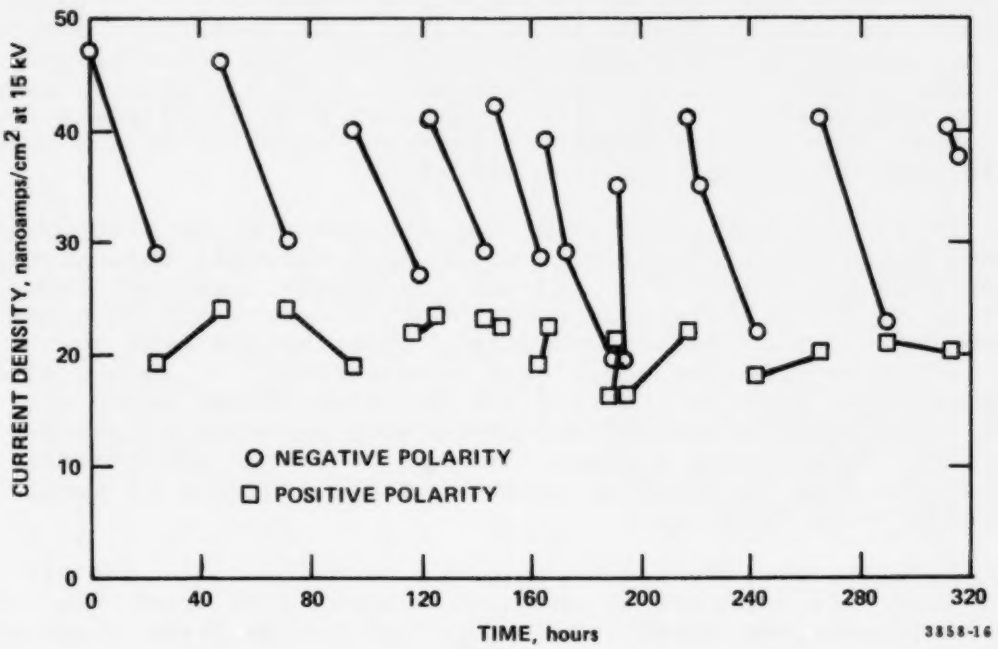

Figure 10. Effect of periodic reversing of corona polarity for various increments of time.

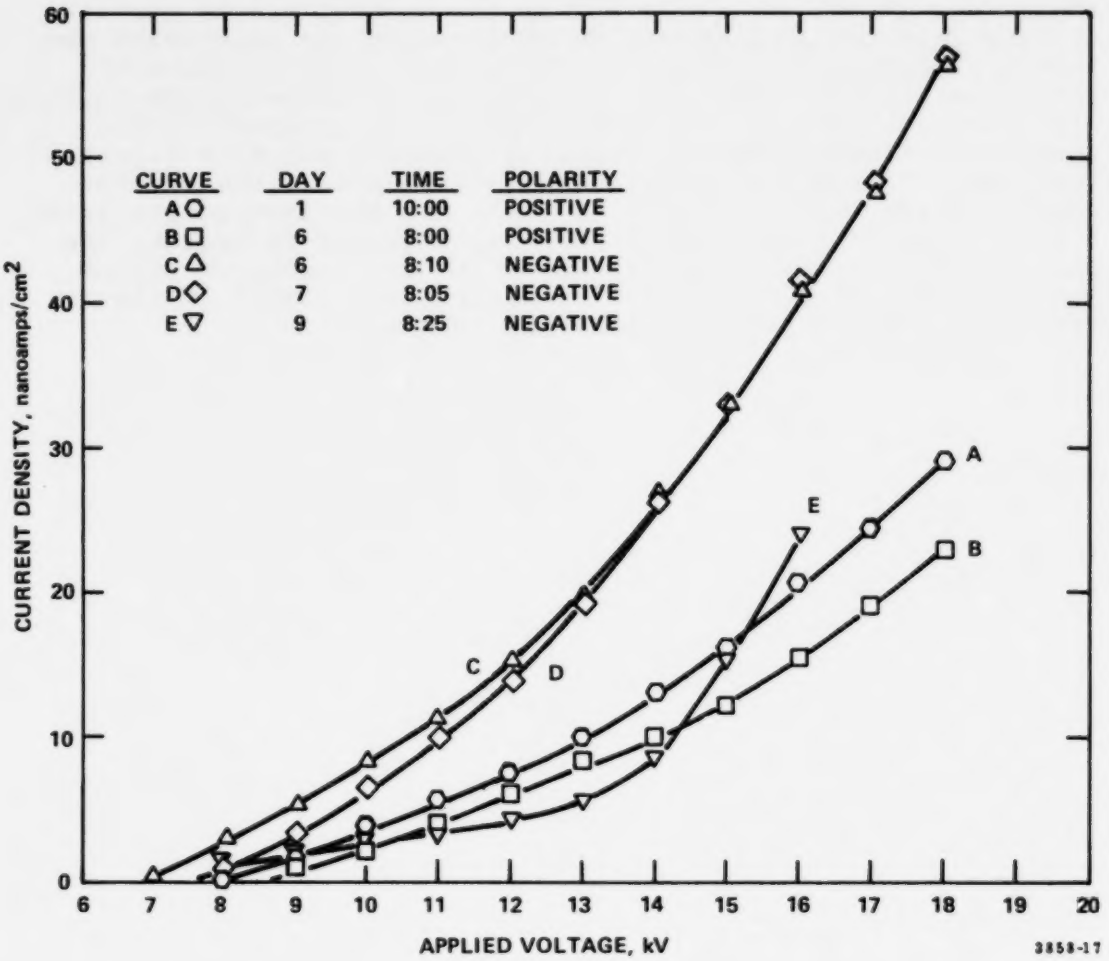

Figure 11. Current density as a function of applied positive or negative voltages.

Figure 8 and D in Figure 9 would also show degradation with additional time of continuous positive polarity corona.

After 120 hours of positive polarity corona had been used, a negative current density-voltage curve was taken, curve C of Figure 11. For the remainder of the experiment, negative polarity was used and curves were obtained after 24 and 72 hours had elapsed, D and E, respectively. The distorted concentration profile of sodium ions in the ash layer due to the initial use of positive polarity produced an interesting effect when the experiment was converted to negative polarity. Note that after 24 hours of continuous negative polarity, the current density-voltage relationship, curve D, had not degraded. This is in contrast to the degradation illustrated by comparing curves A and B in Figure 9. After about 72 hours of negative polarity corona, the current density-voltage curve, E in Figure 11, had degraded to the level of B in Figure 9. The additional time required to degrade the curve under negative polarity was due to the excess of sodium ions available at the "collection plate" as a result of the previously applied positive polarity corona.

SECTION 7

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